OPEN SEAWATER SYSTEM WITH CONTROLLED TEMPERATURE AND SALINITY

William F. Hettler, Jr., Richard W. Lichtenheld, and Herbert R. Gordy
Bureau of Commercial Fisheries
Center for Estuarine and Menhaden Research, Beaufort, North Carolina 28516

MAINTENANCE OF MARINE ORGANISMS IN CAPTIVITY depends on a reliable seawater system that provides an uninterrupted flow of water approaching the constancy and purity of open ocean water. Because most marine laboratories pump water from rivers, bays, or surf zones, the quality of the incoming supply can vary considerably in temperature, salinity, and turbidity.

The seawater system of the Bureau of Commercial Fisheries Biological Laboratory at Beaufort, North Carolina, as described by Talbot (1964), was inadequate for rearing Atlantic menhaden (Brevoortia tyrannus) and for studying their physiology and behavior. Plankton pumped in with the seawater interfered with controlled feeding experiments and caused fouling in the pipes and valves. Fluctuating loads of particulate material in the unfiltered seawater made visual observations difficult; at times visibility into the aquariums was less than 1 foot. Water temperatures usually dropped during the winter to, or near, the lethal limit for menhaden and fluctuated as much as 8° F. above or below the seasonal mean during the colder months. Heating large quantities of seawater with electric immersion heaters was impractical. Occasional clogging of the intake with sea grass, plastic bags, or other debris stopped the flow of water and disturbed experiments. A seawater system that would reduce or eliminate these problems was needed.

The system we selected was "open" (water discarded after a single use) rather than "closed" (water recirculated) because we needed a simple, economical, relatively maintenance-free system that would ensure a constant supply of incoming seawater to flush excretory products. Though closed systems conserve seawater and facilitate the control of temperature and clarity, they have several disadvantages: After seawater has been recirculated for extended periods, nitrates accumulate, pH decreases, bacteria increase, and trace elements are lost. Furthermore, closed systems are more complex because of the need for large storage and filtration capacity and for treatment with alkalizers and sterilizers. We would have had an additional problem in holding menhaden in a closed system. Because juvenile and adult menhaden are filter feeders, their food must be suspended in the water if they are to feed successfully; usually we feed a granulated formula commonly used by hatcheries for fingerlings. The removal of uneaten food after prolonged holding of large quantities of fish would have presented an especially difficult filtration problem.

In our modification of the basic open system described by Talbot (1964), the temperature, salinity, and turbidity can be controlled. Seawater is pumped from submerged filters into two large reservoirs to provide a constant delivery pressure and to furnish reserve water when pumping is temporarily stopped. From the primary storage reservoirs, filtered seawater flows by gravity into secondary reservoirs, where the temperature and salinity are adjusted. Processed water is then available for delivery, by gravity flow, into the laboratory. The purpose of this paper is to present features of our system which may be useful to those planning to construct or improve seawater systems. Sources of the major components are included (table 1).[1]

FILTRATION

Initial attempts to obtain filtered seawater by using the natural bottom as the filtering medium (as suggested by Clark and Eisler, 1964) were unsuccessful. A sea-well was drilled 10 feet from shore, near the laboratory on the sandy slope of a 300-foot-wide, 15-foot-deep channel. Water was pumped through a well screen placed at different depths below the sand-water interface. At depths to 10 feet, only low-salinity water was found. From 10 to 40 feet, the water was of high salinity (30 parts per thousand) but concentrations of ferric hydroxide ($Fe(OH)_3$) were so heavy that the water was unusable without a settling procedure. Clark and Eisler

[1] Mention of trade names in this publication does not imply endorsement by the Bureau of Commercial Fisheries.

TABLE 1.--Sources of special components in seawater system

Item	Number used	Source
Septic tanks, 1,000 gal., concrete-------------	2	Local building contractor.
Well screens, stainless steel------------------	4	UOP-Johnson Division St. Paul, Minnesota.
Sand pack--------------------------------------	10	Jesse S. Morie and Son, Inc. Mauricetown, New Jersey.
Water pump, centrifugal with 3-hp. motor, model WAM.	1	Ace Molded Products Co. Butler, New Jersey.
Reservoirs, 4,700 gal., fiberglass-------------	2	Carolina Fiberglass Products Co. Wilson, North Carolina.
Reservoirs, 500 gal., fiberglass---------------	3	
Salinity controller/recorder, Dynalog model 9760, with temperature-compensated conductivity cell.	1	The Foxboro Co. Foxboro, Massachusetts.
Heat exchanger, Teflon, 650-tube---------------	1	E. I. du Pont de Nemours and Co. Wilmington, Delaware.
Heat exchanger, Teflon, 280-tube---------------	1	
Heat exchanger, Teflon, 160-tube---------------	1	
Water heater, 300,000 B.t.u./hr., including all pipes, valves, other fittings, and labor.	1	Local plumbing contractor.
Air pump, rotary-vane, model 2, 6-7 c.f.m.-----	1	Condé Milking Machine Co., Inc. Sherrill, New York.
Air pump, rotary-vane, model 3, 16-18 c.f.m.---	1	
Water pumps, centrifugal, 6-1/2 g.p.m., model 7004-3.	2	Cole-Parmer Chicago, Illinois.
Temperature controllers, YSI model 63----------	3	

(1964) stated that exposure to air for a week or more is required for precipitation of iron. When sustained pumping for a week continued to yield high concentrations of iron, we abandoned the well and developed an artificial filter.

Artificial filters pose several problems in design, including the type of filtrant (synthetic or natural), the filtering capacity, and the cleaning or renewal procedure. The type of filter system we found to be satisfactory was a prepared sand-bed infiltration gallery (figure 1).

Two filter units have been submerged in the channel adjacent to the laboratory grounds, about 50 feet offshore in 12 feet of water. Each unit consists of a 1,000-gallon concrete septic tank (8 feet long, 4 feet wide, and 5 feet deep) containing two well screens and a sand pack. Each tank has three heavy concrete lids with 2-inch holes for water entry and one light concrete lid for periodic inspection of the sand.

The two well screens in each tank prevent the sand from entering the intake pipes. Each stainless-steel (type 316) screen is of the continuous-slot design (0.020-inch slot opening) and is 3 inches in diameter and 7 feet long. Both screens in each of the tanks are joined with 2-inch unplasticized polyvinyl chloride (PVC) fittings to a single 2-inch hard-rubber pipe leading to the pump. The screens are laid along the bottom in each tank, 2.5 feet apart.

Five tons of graded, coarse, silica sand (grains 0.030 ± 0.002 inch in diameter) was placed around and above the well screens in each tank. The sand pack has a surface area of 32 square feet and is 3.5 feet deep.

The filtering units were installed from a barge. The tanks, with well screens and intake piping in place, were floated and filled with sand. Concrete lids were installed and then the tanks were flooded and lowered to the bottom. They were positioned side by side, parallel with the axis of the channel, by a diver; also, the two pipes leading along the bottom from the filters to the shore were anchored by the diver.

The valves connecting the filter units to the pump were originally above the water level. Air leaked into the system around the stems of the 2-inch PVC ball valves, however, and caused the pump to lose its prime. All valves in the intake line were then placed underwater. They are operated from a pier by extension handles.

A hard-rubber centrifugal pump, driven by a 3-horsepower electric motor, pulls water through the filters and pumps it at the rate of 50 gallons per minute to a height of 24 feet. The pumping output does not increase when the filter bypass valve is opened, an indication that clean sand filters provide a balanced percolation-pumping state. Each filter is back-flushed for 30 minutes twice each week by pumping water from the filter bypass intake back through the filter intake lines, well screens, and sand.

The filtered water is pumped into two 4,700-gallon cylindrical fiberglass reservoirs mounted on a 10-foot-high platform near the pump. Water that is stored in these tanks is continuously and vigorously aerated by a rotary-vane air pump to dispel any supersaturation by air injected through the pump seals into the water as it is temporarily pressurized in the pump. (During several experiments with larval menhaden, embolism and death resulted from air-supersaturated seawater. Aeration during storage eliminates this problem.)

The filtration ability of the system was evaluated by weighing the suspended matter in filtered and unfiltered water. The unfiltered water sample, taken near the pump intake, was representative of the typical particulate load of the channel water. A membrane filter (pore size, 0.45 micron) was used to remove the particulate matter from the water samples. The filtered water had 2.13 milligrams of solids per liter; the unfiltered water had 15.56 milligrams per liter. Although the filtered seawater still contains suspended material and is slightly cloudy, most of the fouling organisms and larger particles are removed by the filter.

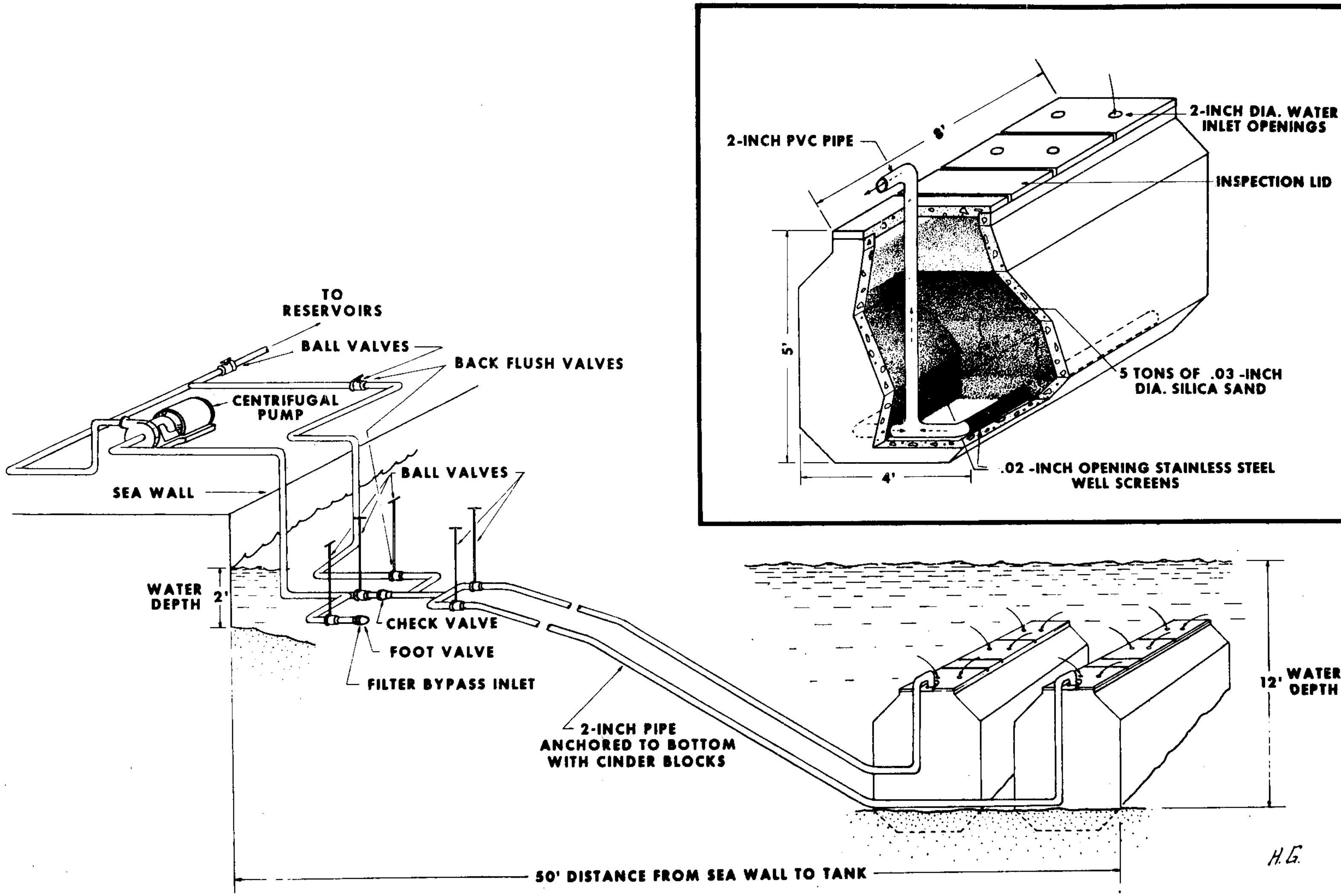


FIGURE 1.--Two submerged filters together furnish about 50 gallons per minute of filtered seawater. The inset shows a cutaway of one 1,000-gallon concrete tank.

SALINITY CONTROL

A recorder-controller regulates the salinity of water entering our aquariums at any level between freshwater and that of the water pumped from the channel. The salinity-control equipment includes an electronic section for sensing and recording, a pneumatic section for controlling a pair of valves that regulate the water flow, and three water reservoirs (figure 2).

The recorder-controller is mounted outside the seawater laboratory. The instrument's conductivity cell is floated in a cradle 50 feet away in the controlled-salinity reservoir. The conductivity (converted to salinity) and temperature of the water in the reservoir are measured by the cell and continuously recorded on a 7-day circular chart. Automatic temperature compensation of the cell for the conversion of conductivity to salinity ranges from 40° to 80° F.

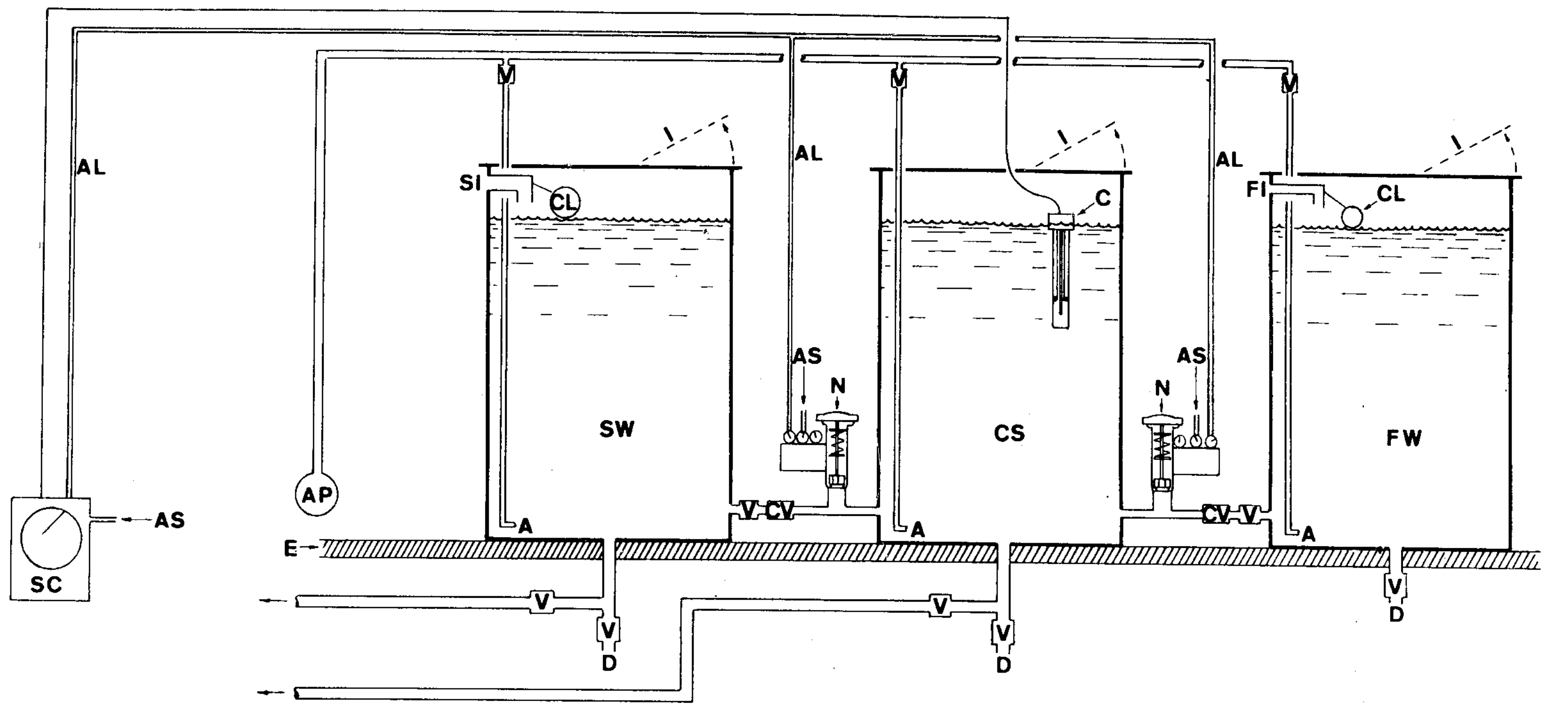
Salinity control is effected by setting a pointer to the desired salinity on the salinity-recording chart. The difference between the desired salinity and the actual salinity is measured by the instrument, and a variable air-pressure signal (between 0 and 20 pounds per square inch) is sent to the seawater and freshwater reservoir valves. This air signal proportionally opens or closes the two PVC valves (1 inch in inside diameter, air-actuated, proportional-flow) that control the flow of seawater and freshwater into the controlled-salinity reservoir. Water flows by gravity into the controlled-salinity reservoir when the valves are opened.

The three 500-gallon cylindrical fiberglass reservoirs (4 feet in diameter, 6 feet high) are enclosed in an elevated platform outside the seawater laboratory; they are 6 feet lower than the primary storage reservoirs, 4 feet above the aquariums. Once seawater has been pumped into the two main storage reservoirs, it flows by gravity through the seawater and the salinity-temperature control reservoirs to the aquariums. One of the three reservoirs--the secondary seawater reservoir--is connected to the main storage reservoirs with 200 feet of 4-inch PVC pipe. Throughout the seawater system, PVC pipes and fittings are used to avoid metallic contamination; the sole exception is one stainless-steel (type 316) 1.5-inch constant-level float valve which admits water from the primary storage reservoirs into the secondary seawater storage reservoir.

The freshwater used to dilute seawater to desired salinities is pumped from a 220-foot well on the island. Water from this well has a hardness (as $CaCO_3$) of about 302 p.p.m. and a conductance of 563 micromhos per centimeter at 77° F. The "salinity" reading in well water is about 0.3 p.p.t. Because the freshwater pumping and distribution system for the entire laboratory is constructed of iron, brass, and copper components, there was no advantage in using nonmetallic fittings in the freshwater portion of the system. The water level in the freshwater reservoir is maintained with a 0.75-inch brass float valve.

The circuit that measures and controls salinity is accurate to ± 0.6 p.p.t. over its range (0 to 40 p.p.t.) as long as the platinum electrodes in the conductivity cell are clean. The cell is cleaned every 2 weeks in a 15-percent HCl solution, and the electrodes are replatinized about every 2 months. No other maintenance of the salinity-control system is normally required. The precision of the salinity control is within 0.1 p.p.t. of the salinity demanded by the pointer. Because of the large mixing reservoir and the precision of the metering valves, there is no oscillation due to overshooting or undershooting the selected salinity with freshwater or seawater.

The salinity of the water delivered to the laboratory can easily be raised or lowered. At a flow of 5 gallons per minute from the controlled-salinity reservoir to the aquariums, the water can be changed at 10 p.p.t. per hour. If a more rapid change is necessary, the entire reservoir can be emptied and refilled to the required salinity in less than 1 hour. The manufacturer of the instrument can provide an accessory that will permit



A	- AIR OUTLET FOR AERATION, CIRCULATION	E	- ELEVATED AND ENCLOSED PLATFORM
AL	- 0-20 P.S.I. COPPER AIR LINE	FI	- FRESH-WATER INLET FROM WELL
AP	- ROTARY-VANE AIR PUMP	FW	- 500-GAL. FRESH-WATER RESERVOIR
AS	- PRESSURE-REGULATED AIR SUPPLY	I	- INSPECTION LID
C	- TEMPERATURE-COMPENSATED CONDUCTIVITY CELL	N	- PROPORTIONAL-FLOW NEEDLE VALVE
CL	- CONSTANT-LEVEL FLOAT VALVE	SC	- SALINITY RECORDER/CONTROLLER
CS	- 500-GAL. CONTROLLED-SALINITY RESERVOIR	SI	- SEA-WATER INLET FROM STORAGE RESERVOIRS
CV	- CHECK VALVE	SW	- 500-GAL. SEA-WATER RESERVOIR
D	- DRAIN OUTLET	V	- PVC VALVE

FIGURE 2.--Salinity control is effected by proportionally mixing fresh and seawater. The salinity and temperature control circuits are illustrated separately for clarity.

controlled fluctuations in salinity over any time scale to simulate ebb and flood tides.

A limitation of this system is that it provides one salinity to the laboratory at a time. When it is necessary to hold fish at different salinities concurrently, freshwater and controlled-salinity water valves at each aquarium are adjusted to provide a mixture of the required salinity. Once an equilibrium is established, the salinity of the mixture remains nearly constant, provided that the flow rate from both valves is uninterrupted.

The system does not provide salinities above that of the incoming seawater. If it were essential to have salinities above the source values, a large brine reservoir could be substituted for the seawater reservoir. However, the high cost of synthetic sea salts would require altering the open system to a semiclosed system.

TEMPERATURE CONTROL

The water-heating unit consists of three heat exchangers, a hot-water heater, piping, temperature controllers, and motorized valves (figure 3).

Corrosion-resistant heat exchangers are used in the seawater, freshwater, and controlled-salinity reservoirs; they are 8 feet long and contain 650, 280, and 160 individual tubes, respectively (figure 4). The individual tubes (0.10-inch outside diameter, 0.08-inch inside diameter) are made of Teflon, a fluorocarbon resin. Teflon was used because it resists scale buildup and is nearly inert. A disadvantage is its low thermal conductivity, which is about one-third that of a metal conductor. This disadvantage is overcome by increasing the surface area of the heat exchanger with numerous small tubes. The coils in the seawater, freshwater, and controlled-salinity reservoirs have 145.6, 61.6, and 35.2 square feet of heat-transfer surface, respectively. The tubes in each of the heat exchangers are braided together and joined at each end into an integral "honeycomb" tube sheet. The honeycomb is contained within a stainless-steel (type 316) end that has a standard male threaded pipe fitting. Each coil is suspended below the water surface by two high-temperature-resistant chlorinated polyether thermoplastic pipes, through which hot water flows to and from the heater.

Freshwater, heated to 180° F. by an oil-fired (300,000 British thermal units per hour) heater, is circulated through the heat exchangers. The heater is below the elevated platform holding the three reservoirs. The flow pressure is provided by a circulating pump in the return line. A motorized valve controls the flow of hot water into each heat exchanger. Sensors for the temperature controllers are mounted underwater in the reservoirs, about 3 feet from the coils. When the water temperature of a reservoir drops below the level set into its thermostat, the motorized valve opens, allows hot water to pass through the coil until the desired temperature is reached, and then closes.

A small volume of temperature-regulated water is continuously recirculated between the reservoirs and the laboratory to maintain heated water at the outlets to the experimental tanks during periods of low water use. Water is circulated with magnetically driven centrifugal pumps with polypropylene bodies and impellers, rated at 6.5 gallons per minute.

Circulation in the three reservoirs prevents stratification. Vigorous mixing of the water is achieved by pumping air to the bottom of each reservoir with a high-volume, low-pressure rotary-vane air pump. This air not only functions to distribute the heat and salt content, but also to bring the water to 100 percent oxygen saturation.

In the seawater reservoir, from which the greatest volume of water is used, the temperature can be maintained automatically within ± 1° F. of the desired temperature. In the controlled-salinity and freshwater reservoirs, which have smaller heat exchangers, the temperature can be held to within ± 0.7° F. The amplitude of the oscillation around a given temperature can be regulated by adjustment of a flow-regulating valve in each circuit. By reducing the flow of hot water through

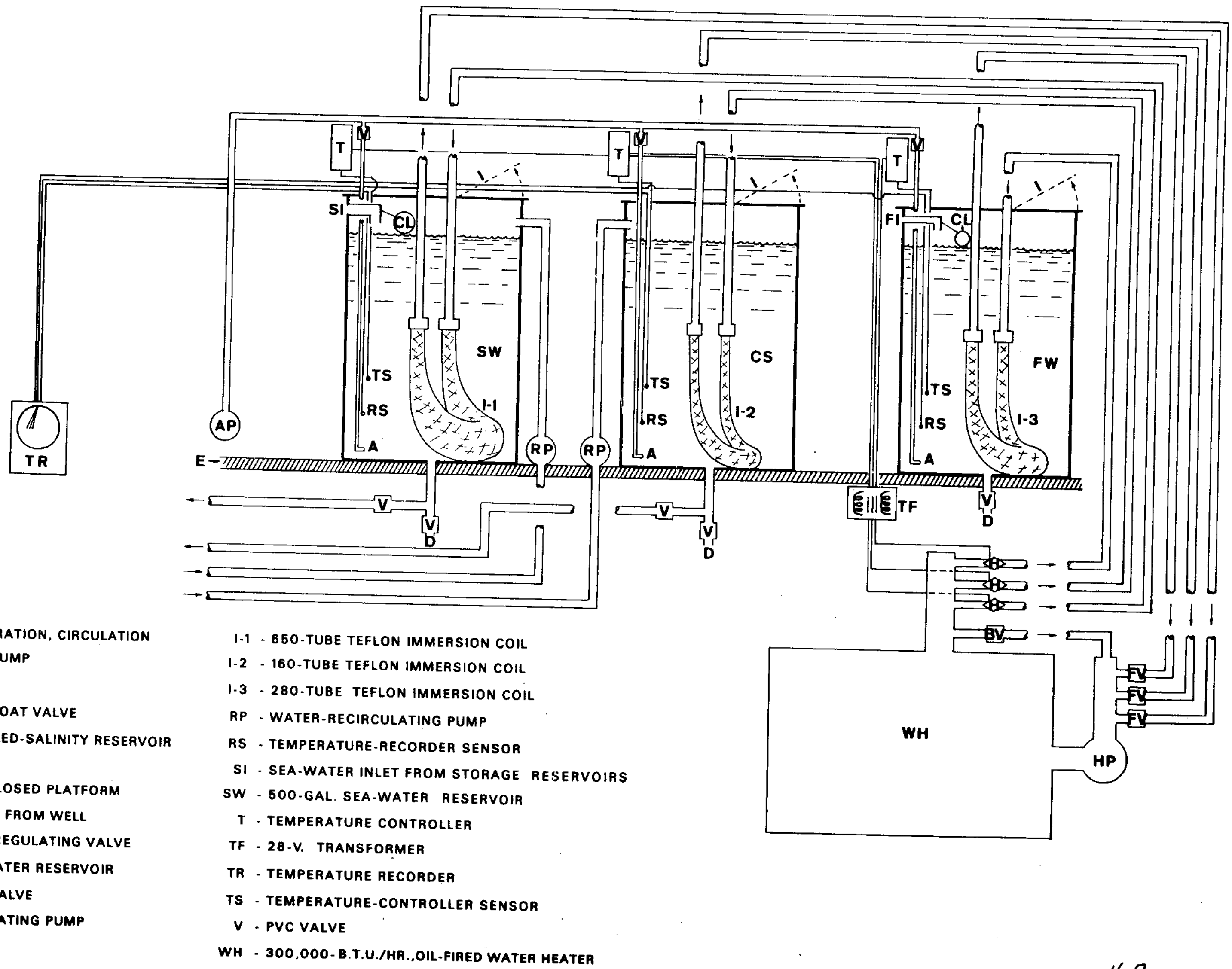


FIGURE 3.--Water in the three reservoirs is heated with 180° F. freshwater passing through Teflon heat exchangers. Temperature-regulated water is circulated to the laboratory outlets (not shown) from the seawater and controlled-salinity reservoirs. Water heated in the freshwater reservoir is used only for salinity control (see figure 2).

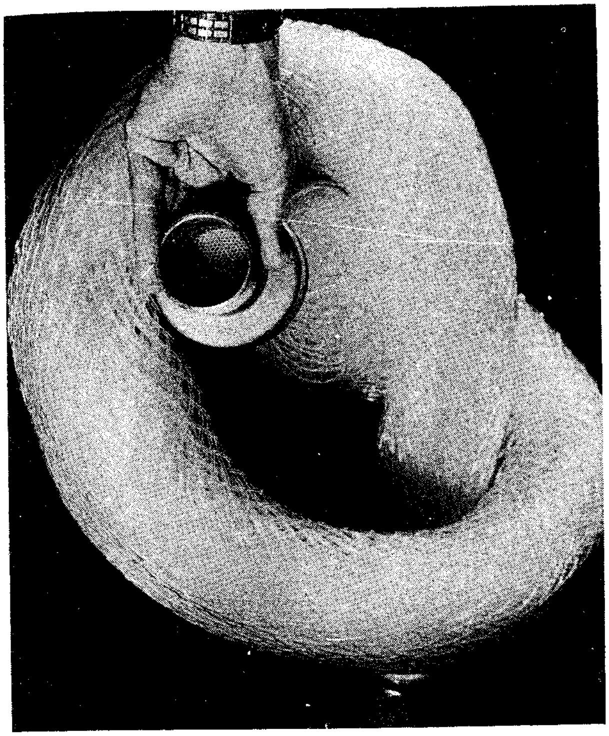


FIGURE 4.--A 650-tube Teflon heat exchanger is used to heat seawater. Hot water flows through the 0.08-inch (inside diameter) tubes.

a heat exchanger, the oscillation can be dampened; however, the heating capacity is then reduced. Fluctuations, as much as ± 2° F., around the selected temperatures are insignificant because these oscillations are diminished when temperature-regulated water mixes with water already in the aquariums. For example, the water temperature in one 560-gallon aquarium was maintained at 68° ± 0.2° F. for more than a month. The flow rate of "new" water into this tank was approximately 5 gallons per minute. The incoming water temperature from the primary storage reservoirs ranged from 51° to 66° F. during this test. When the heating system was tested for its capacity to heat rapidly, 500 gallons of 54° F. seawater was heated to 70° F. in 20 minutes with the 650-tube immersion coil and 180° F. heating water; that is, the temperature in the 500-gallon reservoir was raised 0.75° F. per minute.

To get fluctuating temperatures with this heating system, two temperature controllers and a timeclock are necessary. The minimum and maximum temperatures desired would determine the two thermostat settings. The clock would alternately activate the thermostats for any chosen length of time during a 24-hour cycle; for example, a cycle consisting of 6 hours of elevated temperature, followed by 6 hours of lowered temperature.

The system has reliably provided filtered temperature- and salinity-regulated water since November 1969. The only interruptions have been due to electric-power outages. We have successfully held juvenile and adult menhaden in the laboratory since the system became operational.

ACKNOWLEDGMENTS

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